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(11) **EP 1 267 490 A2**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
18.12.2002 Bulletin 2002/51

(51) Int Cl.7: **H03H 9/64**

(21) Application number: **02291397.4**

(22) Date of filing: **06.06.2002**

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU
MC NL PT SE TR
Designated Extension States:
AL LT LV MK RO SI

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(30) Priority: 12.06.2001 JP 2001177423
15.04.2002 JP 2002112263

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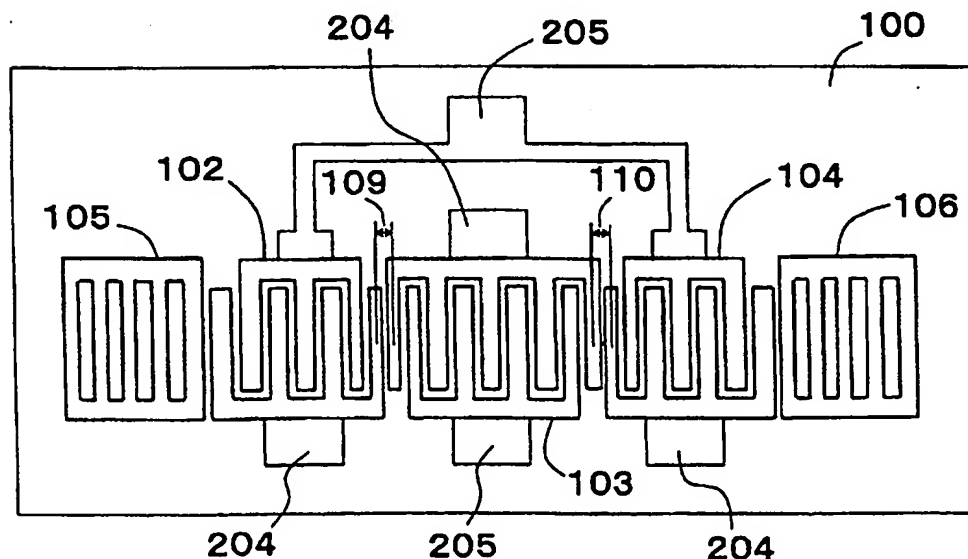
(54) **Longitudinally-coupled resonator surface-acoustic wave filter and communications apparatus using the same**

(57) In a SAW filter (101) comprising a piezoelectric substrate (100) and at least two IDTs (102-4) formed in the direction along which a SAW propagates on the pi-

ezoelectric substrate, at least one of the IDTs has an electrode finger wherein the metallization ratio of the electrode finger is different from that of the other electrode fingers of the IDT.

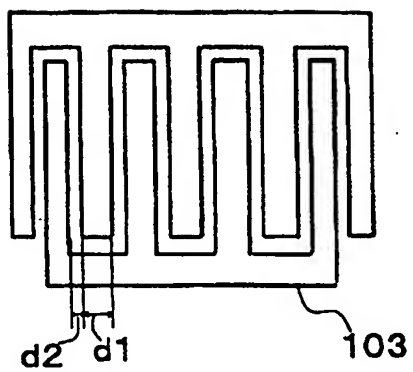
FIG. 1A

101



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FIG. 1B



Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to a longitudinally-coupled resonator surface-acoustic-wave (SAW) filter and to a communications apparatus using the same.

2. Description of the Related Art

[0002] In recent years, communications apparatuses such as mobile phones often have transmission frequency band and reception frequency band, which are near each other, due to increased users and diversification of services. Some communications apparatuses require attenuation larger than a predetermined level quite near the passband thereof for preventing interference from other communications apparatuses. Accordingly, SAW filters widely used as band-pass filters for an RF stage of a mobile phone require attenuation larger than the predetermined level quite near the passband.

[0003] For SAW filters, a function of balance/unbalance signal conversion, which is a so-called balun function, becomes increasingly required for reducing the number of parts. For example, a longitudinally-coupled resonator SAW filter having the function of balance/unbalance signal conversion is disclosed in Japanese Unexamined Patent Application Publication No. 5-267990.

[0004] However, when using the known above-described longitudinally-coupled resonator SAW filter, a deterioration of the shoulder characteristic, which is called a transversal response (a deterioration of the steepness of frequencies), is seen at the higher frequency-side of the passband. Subsequently, the known longitudinally-coupled resonator SAW filter cannot achieve sufficient attenuation at the higher frequency-side of the passband, which is required for a communications apparatus in a personal communication system (PCS). For solving such problems, a ladder-type SAW filter is disclosed in Japanese Unexamined Patent Application Publication No. 10-126212 for example. This filter has large attenuation at the higher frequency-side of the passband. However, this ladder-type SAW filter cannot have the function of balance/unbalance signal conversion. That is to say, it is difficult for the known SAW filter to have both sufficient attenuation at the higher frequency-side of the passband and the function of balance/unbalance signal conversion.

SUMMARY OF THE INVENTION

[0005] Accordingly, it is an object of the present invention to provide a longitudinally-coupled resonator SAW filter which can substantially reduce the transversal response compared to the known SAW filter, and which has the function of balance/unbalance signal conver-

sion.

[0006] According to an aspect of the present invention, a longitudinally-coupled resonator surface-acoustic-wave (SAW) filter comprises a piezoelectric substrate and at least two interdigital transducers (IDTs) provided on the piezoelectric substrate along the direction in which a surface acoustic wave propagates. At least one of the IDTs has an electrode finger wherein the metallization ratio of the electrode finger is different from that of other electrode fingers of the IDT.

[0007] Preferably, in the longitudinally-coupled resonator SAW filter, at least one IDT which neighbours another IDT has one or more electrode fingers, in a region thereof stretching from the end neighboring the other IDT to about one-fourth of the way along itself, whose metallization ratio is different from that of other electrode fingers of the IDT.

[0008] Preferably, in the longitudinally-coupled resonator SAW filter, at least one of the IDTs has electrode fingers wherein the metallization ratio of the electrode fingers is continuously varied in the direction along which a surface acoustic wave propagates.

[0009] Accordingly, the longitudinally-coupled resonator SAW filter has a reduced transversal response and a large attenuation at the higher frequency-side of the passband. Further, by forming the part wherein the metallization of the electrode fingers is continuously varied in the direction along which a SAW propagates in the region stretching from the end neighboring another IDT to about one-fourth of the way along the IDT, the insertion loss in the passband is not increased. Further, by continuously varying the metallization ratio of the electrode fingers in the surface acoustic propagation direction the insertion loss within the passband is not increased and a better effect of the present invention can be obtained.

[0010] According to another aspect of the invention, a communications apparatus comprising the longitudinally-coupled resonator SAW filter mounted therein is provided. By using the longitudinally-coupled resonator SAW filter of the present invention, the communications apparatus can achieve good communications quality and high reliability.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011]

FIG. 1A schematically shows a longitudinally-coupled resonator surface-acoustic-wave (SAW) filter according to a first embodiment of the present invention;

FIG. 1B illustrates the metallization ratio of the longitudinally-coupled resonator SAW filter;

FIG. 2 shows a graph illustrating the variation of the metallization ratio of IDTs of the longitudinally-coupled resonator SAW filter according to the first embodiment of the present invention;

FIG. 3 shows a graph illustrating the frequency-amplitude characteristic of the longitudinally-coupled resonator SAW filter according to the first embodiment of the present invention;

FIG. 4 shows a graph illustrating the frequency-amplitude characteristic of a longitudinally-coupled resonator SAW filter having a known configuration; FIG. 5 shows a graph illustrating the variation of the metallization ratio of IDTs of a longitudinally-coupled resonator SAW filter according to a second embodiment of the present invention;

FIG. 6 shows a graph illustrating the frequency-amplitude characteristic of the longitudinally-coupled resonator SAW filter according to the second embodiment of the present invention;

FIG. 7 shows a graph illustrating the variation of the metallization ratio of IDTs of a longitudinally-coupled resonator SAW filter according to a third embodiment of the present invention;

FIG. 8 shows a graph illustrating the frequency-amplitude characteristic of the longitudinally-coupled resonator SAW filter according to the third embodiment of the present invention;

FIG. 9 schematically shows a longitudinally-coupled resonator SAW filter according to a fourth embodiment of the present invention;

FIG. 10 schematically shows a longitudinally-coupled resonator SAW filter according to a fifth embodiment of the present invention;

FIG. 11 schematically shows a longitudinally-coupled resonator SAW filter according to a sixth embodiment of the present invention;

FIG. 12 schematically shows a longitudinally-coupled resonator SAW filter according to a seventh embodiment of the present invention; and

FIG. 13 is a block diagram schematically showing a communications apparatus having a longitudinally-coupled resonator SAW filter according to the present invention mounted therein.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0012] A longitudinally-coupled resonator surface-acoustic-wave (SAW) filter according to embodiments of the present invention will now be described with reference to FIGs. 1A, 1B, 2 to 12.

[0013] FIG. 1A shows the configuration of a longitudinally-coupled resonator surface-acoustic-wave (SAW) filter 101 (hereinafter referred to as the filter 101), which is an example of an EGSM-Rx filter, according to a first embodiment. Incidentally, the EGSM-Rx filter will also be used as an example in the second to seventh embodiments.

[0014] The filter 101 comprises: a $40 \pm 5^\circ$ Y-cut X-propagating LiTaO_3 substrate 100 (hereinafter referred to as the substrate 100), which is a piezoelectric substrate; ground terminals 204; signal terminals 205; an IDT 102,

an IDT 103, and an IDT 104, each having a plurality of electrode fingers made of aluminum connected to the ground terminals 204 and a plurality of electrode fingers made of aluminum connected to the signal terminals 205; a reflector 105; and a reflector 106.

[0015] The electrode fingers of the IDTs 102 and 104 connected to the ground terminals 204 are opposite to the electrode fingers thereof connected to the signal terminals 205. The reflectors 105 and 106 are disposed so as to sandwich the IDTs 102, 103, and 104 therebetween. The IDTs 102 and 104 are connected in parallel to the same signal terminal 205.

[0016] As shown in the same drawing, the pitch of several of the electrode fingers of the neighboring parts of IDTs 102 and 103, and the pitch of several of the electrode fingers of the neighboring parts of IDTs 103 and 104 are narrower than that of the electrode fingers of the other parts of the IDTs. These electrode fingers with narrower pitch are called narrow-pitch electrode fingers. It should be noted that, in FIG. 1A, the number of electrode fingers is reduced for simplification.

[0017] In the filter 101, the metallization ratio of the IDTs is varied. The metallization ratio can be expressed by the equation:

$$d = d1 / (d1 + d2),$$

wherein the width of the electrode finger is indicated as $d1$ and the width of a gap between the electrode fingers is indicated as $d2$ as shown in FIG. 1B.

[0018] FIG. 2 shows a graph showing the metallization ratio of the IDTs 102, 103, and 104, which continuously varies from 0.54 to 0.73. More specifically, the metallization ratio of the IDT 102 continuously varies from 0.54 to 0.73 in the direction from the left to the right as shown in Fig. 1A. For the IDT 103, the metallization ratio thereof continuously varies from 0.73 to 0.54 along the direction from the left to the center, and further varies from 0.54 to 0.73 along the direction from the center to the right. For the IDT 104, the metallization ratio thereof continuously varies from 0.73 to 0.54 along the direction from the left to the right.

[0019] When the wavelength of the filter 101 that is determined by the pitch of the narrow-pitch electrode fingers is λ_2 , and when the wavelength thereof that is determined by the pitch of the other electrode fingers is λ_1 , the configuration of the filter 101 can be designated as described below:

Interdigital width W : $47.7\lambda_1$

Number of electrode fingers of the IDT 102: 27 (four electrode fingers on the right-side thereof are narrow-pitch electrode fingers)

Number of electrode fingers of the IDT 103: 35 (four electrode fingers on the right-side thereof and four electrode fingers on the left-side thereof are narrow-pitch electrode fingers)

Number of electrode fingers of the IDT 104: 27 (four electrode fingers on the left-side thereof are narrow-pitch electrode fingers)

IDT wavelength λ_{11} : 4.19 μm , λ_{12} : 3.86 μm

Wavelength λ_R of the reflectors 105 and 106: 4.26 μm

Number of reflectors 105 and 106: 120

Gap between IDTs (109 and 110 in FIG. 1A): $0.50\lambda_{12}$

Gap between IDTs and reflectors: $0.52\lambda_R$

Metallization ratio of the reflectors: 0.55

Film thickness of the electrodes: $0.08\lambda_{11}$

[0020] FIG. 3 shows the frequency-amplitude characteristic of the filter 101 according to the first embodiment. For comparison purposes, FIG. 4 shows the frequency-amplitude characteristic of a longitudinally-coupled resonator SAW filter having a known configuration, whose IDT metallization ratio is set constant at 0.73. The configuration of this known longitudinally-coupled resonator SAW filter is otherwise the same as that of the filter 101. However, to perform impedance matching, the interdigital width is changed from $47.7\lambda_{11}$ to $35.8\lambda_{11}$.

[0021] As shown in FIG. 3, the attenuation at the higher frequency than the passband, that is, from 990 to 1020 MHz (the diagonally shaded area), is improved by about 4 dB in comparison with FIG. 4, since the transversal response is reduced because the metallization ratio of the electrode fingers is continuously varied in the direction along which a SAW is propagated. Further, the width of the passband from the through level to 4 dB becomes wider, by as much as about 0.5 MHz, than in the case of the known filter. Accordingly, a longitudinally-coupled resonator SAW filter having a reduced transversal response and an improved attenuation at the higher frequency-side of the passband can be obtained.

[0022] In the first embodiment, the metallization ratio of all of the IDTs 102, 103, and 104 is continuously varied. However, the same effect as in the first embodiment can be obtained when the metallization ratio of only some of the IDTs is varied.

[0023] FIG. 5 is a graph showing the variation of the IDTs of a longitudinally-coupled resonator SAW filter according to a second embodiment.

[0024] In the second embodiment, the metallization ratio of the IDT 103 is not varied while the metallization of the IDTs 102 and 104 is continuously varied. More specifically, the metallization ratio of the electrode fingers of the IDT 102 is continuously varied from 0.54 to 0.73 from the left to the right as shown in Fig. 1A. The metallization ratio of the electrode fingers of the IDT 104 is continuously varied from 0.73 to 0.54 from the left to the right. The metallization ratio of the IDT 103 is set constant at 0.73. The configuration of the filter is the same as in the case of the first embodiment except the way the metallization ratio is varied and the fact that the interdigital width between the IDTs is set at $40.5\lambda_{11}$.

[0025] FIG. 6 shows the frequency-amplitude characteristic of the filter according to the second embodiment.

The attenuation at the higher frequency-side of the passband, that is, from 990 to 1020 MHz (the diagonally shaded area) is improved and the width of the passband from the through level to 4 dB becomes wider as much as about 2 MHz than in the case of the known filter. Thus, according to the second embodiment where the metallization ratio of some of the IDTs is varied, the same effect as in the case of the first embodiment can be obtained.

[0026] In the first and second embodiments, the metallization ratio of the electrode fingers is continuously varied. However, when the metallization is varied, not in a continuous manner, the same effect as in the cases of the first and second embodiments can be obtained.

[0027] FIG. 7 shows a graph illustrating the variation of the metallization ratio of the IDTs of a longitudinally-coupled resonator SAW filter according to a third embodiment where the metallization ratio of the electrode fingers is non-continuously varied. More specifically, though the basic metallization ratio of the IDTs 102 and 104 is set at 0.73, the metallization ratio falls to 0.584 at every third electrode finger. The metallization of the IDT 103 is set constant at 0.73. The configuration of the filter is the same as in the cases of the first and second embodiments except the way the metallization ratio is varied and the fact that the interdigital width between the IDTs is set at $40.5\lambda_{11}$.

[0028] FIG. 8 shows the frequency-amplitude characteristic of the longitudinally-coupled resonator SAW filter according to the third embodiment. The filter according to this embodiment is not as effective as the filters according to the first and second embodiments. However, the attenuation thereof at the higher frequency-side of the passband, that is, from 990 to 1020 MHz (the diagonally shaded area) is improved in comparison with the known case.

[0029] Thus, the longitudinally-coupled resonator SAW filter according to the third embodiment has reduced transversal response and an improved attenuation at the higher frequency-side of the passband, since the metallization ratio of the electrode fingers is non-continuously varied. When the metallization ratio is non-continuously varied, the IDTs also become non-continuous, and the insertion loss in the passband grows larger. Therefore, it is preferable to vary the metallization ratio continuously as in the first and second embodiments.

[0030] In the first to third embodiments of the present invention, the metallization ratio of all of the electrode fingers is varied. However, by forming a part wherein the metallization ratio of the electrode fingers is changed in an area stretching the neighboring part of the IDT to about one-fourth of the way along the IDT, the transversal response is reduced and the attenuation at the higher frequency-side of the passband becomes larger.

[0031] In the first to third embodiments, the $40\pm 5^\circ$ Y-cut X-propagating LiTaO_3 substrate is used. However, other substrates can be used, for example, a 64 to 72°

Y-cut X-propagating LiNbO₃ substrate, or a 41° Y-cut X-propagating LiNbO₃ substrate may be used to obtain the same effect as in the above-described embodiments. Further, the longitudinally-coupled resonator SAW filter of the present invention has three IDTs. However, the filter may be configured otherwise to obtain the same effect as in the above-described embodiments. For example, the filter may have two IDTs, or may have four or more IDTs to obtain the same effect as in the above-described embodiments. Further, the same effect can be obtained when two filters of the present invention are connected in series. Further, one-terminal pair SAW resonators may be connected in series or in parallel.

[0032] The longitudinally-coupled resonator SAW filter shown in the first to third embodiments may be used for a longitudinally-coupled resonator SAW filter having a function of balanced/unbalanced conversion of a signal. Accordingly, a longitudinally-coupled resonator SAW filter having the function of balance/unbalance signal conversion and large attenuation at the higher frequency-side of the passband can be obtained.

[0033] FIGs. 9 to 12 show the configuration of the longitudinally-coupled resonator SAW filter of the present invention having the function of balance/unbalance signal conversion.

[0034] FIG. 9 shows a longitudinally-coupled resonator SAW filter 301 having the function of balance/unbalance signal conversion, according to a fourth embodiment of the present invention. The filter 301 comprises two longitudinally-coupled resonator SAW filters, F1 and F2, which are configured substantially the same as the filter 101 in the first embodiment shown in FIG. 1A and which are connected in parallel. The filter 301 is different from the filter 101 insofar as the IDT 306 of the three IDTs (305, 306, and 307 designated from the left in Fig.9) in filter F2 is disposed top side down. In the filter 301, one of the opposing groups of electrode fingers of the IDTs 302, 304, 305, and 307 is connected to an unbalanced terminal 201, one of the opposing groups of electrode fingers of an IDT 303 is connected to a balanced terminal 202, and one of the opposing groups of electrode fingers of the IDT 306 is connected to a balanced terminal 203.

[0035] FIG. 10 shows a longitudinally-coupled resonator SAW filter 401 having the function of balance/unbalance signal conversion according to a fifth embodiment of the present invention. The filter 401 is configured substantially the same as the filter 101 in the first embodiment, and has a characteristic in the way electrode fingers of an IDT 403 of the three IDTs (402, 403, and 404 designated from the left in Fig.10) are connected to the balanced terminals and to the unbalanced terminal. That is to say, one of the opposing groups of electrode fingers of the IDT 403 is connected to the balanced terminal 202, and the other group is connected to the balanced terminal 203. Further, one of the opposing groups of electrode fingers of IDTs 402 and 404 is connected to the unbalanced terminal 201.

[0036] FIG. 11 shows a longitudinally-coupled resonator SAW filter 501 having the function of balance/unbalance signal conversion according to a sixth embodiment of the present invention. The basic configuration of the filter 501 is the same as that of the filter 101 of the first embodiment. However, the filter 501 is different from the filter 101 insofar as an IDT 504 of the three IDTs (502, 503, and 504 designated from the left in Fig.11) is disposed top side down, and electrodes near the center of the IDT 503 are reversed so that the neighboring electrodes are disposed in the same direction. In the filter 501, one of the opposing groups of electrode fingers of IDTs 502 and 504 is connected to the unbalanced terminal 201, and one of the opposing groups of electrode fingers of IDT 503, the group on the left of the reversed electrodes, is connected to the balanced terminal 202. Further, the other group of electrode fingers of IDT 503, the group on the right of the reversed electrodes, is connected to the balanced terminal 203.

[0037] FIG. 12 shows a longitudinally-coupled resonator SAW filter 601 having the function of balance/unbalance signal conversion according to a seventh embodiment of the present invention. The basic configuration of the filter 601 is the same as that of the filter 101 of the first embodiment. However, the filter 601 is different from the filter 101 insofar as IDT 604 of the three IDTs (602, 603, and 604 designated from the left in Fig. 12) is disposed top side down. In the filter 601, one of the opposing groups of electrode fingers of the IDT 602 is connected to the balanced terminal 202. Further, one of the opposing groups of electrode fingers of the IDT 604 is connected to the balanced terminal 203, and one of the opposing groups of electrode fingers of the IDT 603 is connected to the unbalanced terminal 201.

[0038] As has been described from the fourth to seventh embodiments, the longitudinally-coupled resonator SAW filter comprises the function of balance/unbalance signal conversion. Accordingly, a longitudinally-coupled resonator SAW filter that has the function of balance/unbalance signal conversion and that achieves large attenuation at the higher frequency-side of the passband can be obtained.

[0039] FIG. 13 shows a block diagram schematically illustrating a communications apparatus 160 having the longitudinally-coupled resonator SAW filter according to the present invention mounted therein.

[0040] In FIG. 13, a duplexer 162 is connected to an antenna 161. A longitudinally-coupled resonator SAW filter 164 and an amplifier 165 are connected between the duplexer 162 and a receiving mixer 163. Further, an amplifier 167 and a longitudinally-coupled resonator SAW filter 168 are connected between the duplexer 162 and a transmitting mixer 166. When the amplifier 165 can handle a balanced signal as in this example, a communications apparatus having suitable communications quality and high reliability can be obtained by using the longitudinally-coupled resonator SAW filter according to the present invention can be used as the filter 164.

[0041] Although the present invention has been described above in terms of detailed features of preferred embodiments thereof, it is to be understood that modifications and developments of the embodiments can be made while remaining within the scope of the present invention as defined in the appended claims. 5

Claims

1. A longitudinally-coupled resonator surface-acoustic-wave (SAW) filter (101) comprising:

a piezoelectric substrate (100); and
at least two interdigital transducers (IDTs) (102-4) provided on the piezoelectric substrate along the direction in which a surface acoustic wave propagates, 15

wherein at least one of the IDTs has an electrode finger whose metallization ratio is different from that of other electrode fingers of the IDT. 20
2. A longitudinally-coupled resonator SAW filter according to Claim 1, 25
wherein at least one IDT neighboring a further IDT has at least one electrode finger, in a region stretching from the end neighboring said further IDT to about one-fourth of the way along, wherein the metallization ratio of the at least one electrode finger is different from that of other electrode fingers of the IDT. 30
3. A longitudinally-coupled resonator SAW filter according to one of Claims 1 and 2, 35
wherein at least one of the IDTs has electrode fingers wherein the metallization ratio of the electrode fingers is continuously varied in the direction along which a surface acoustic wave propagates. 40
4. A communications apparatus comprising a longitudinally-coupled resonator SAW filter (101) according to any one of Claims 1 to 3 mounted therein. 45

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FIG. 1A

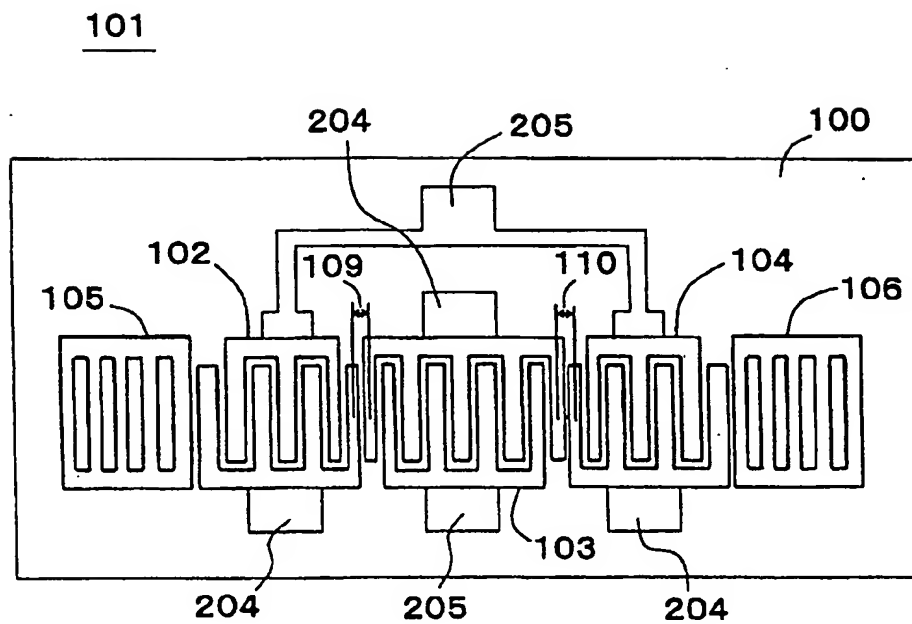


FIG. 1B

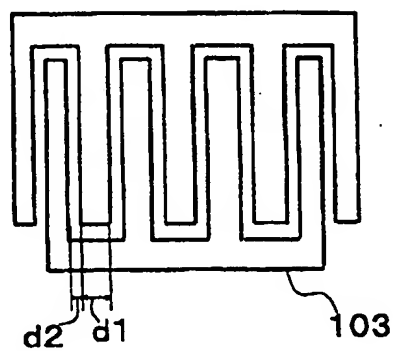


FIG. 2

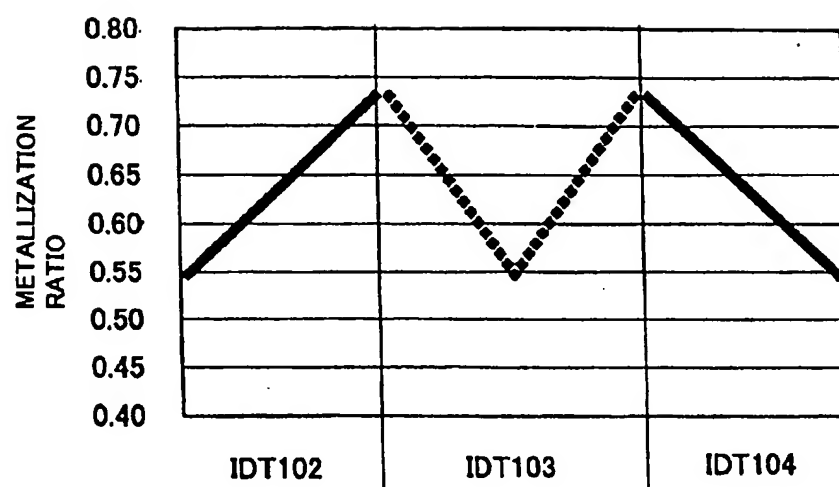


FIG. 3

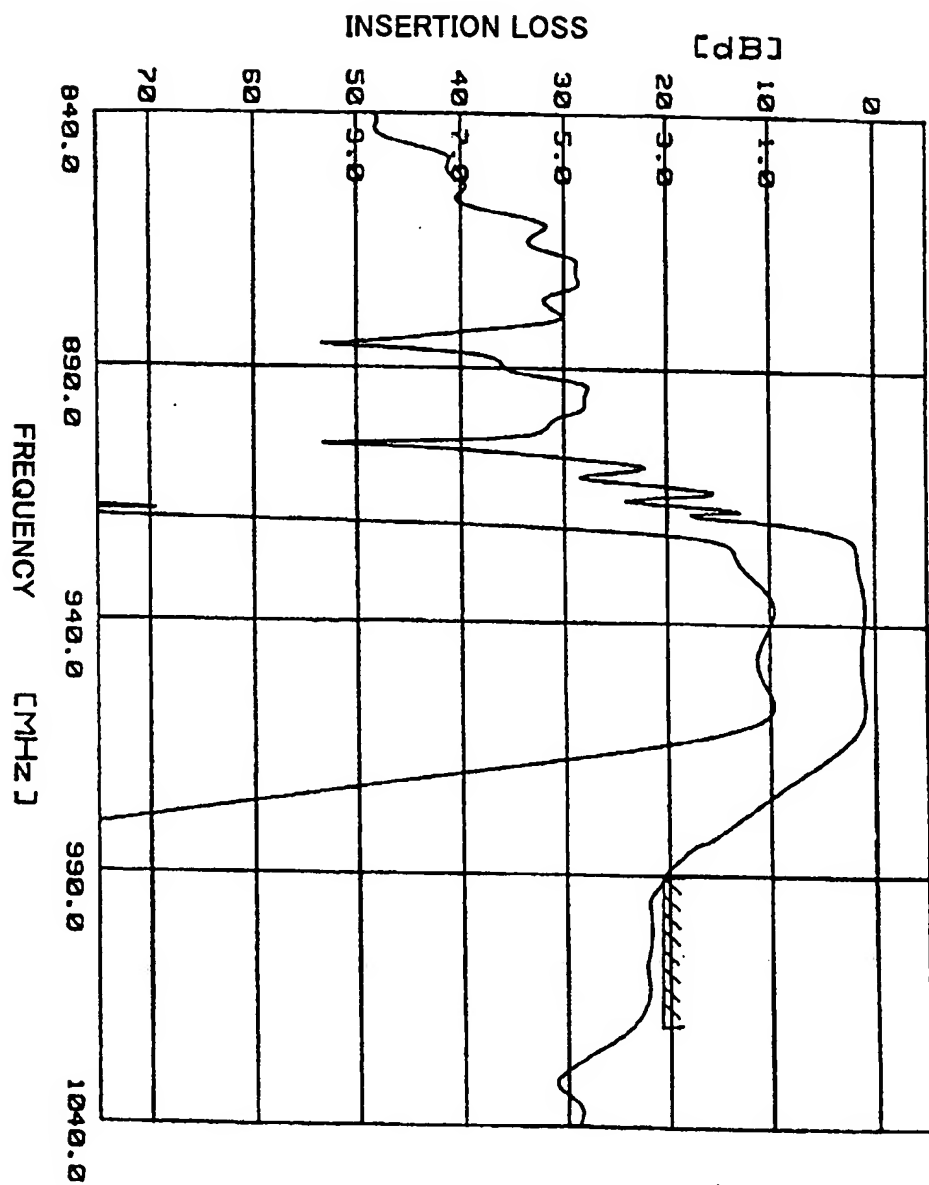


FIG. 4

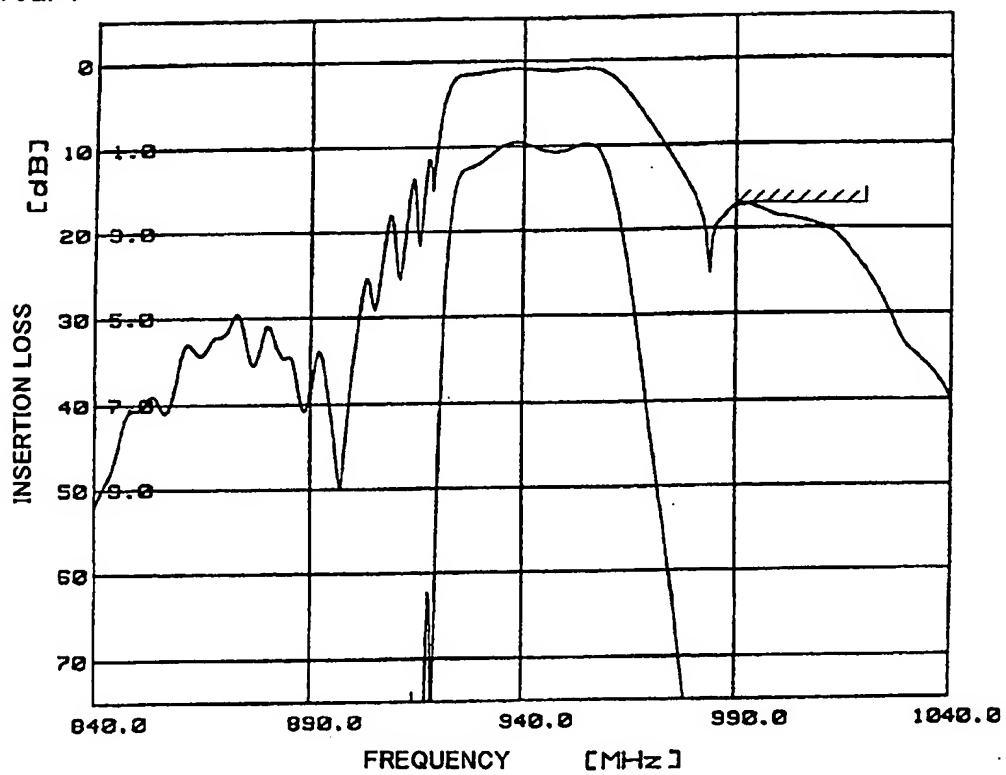


FIG. 5

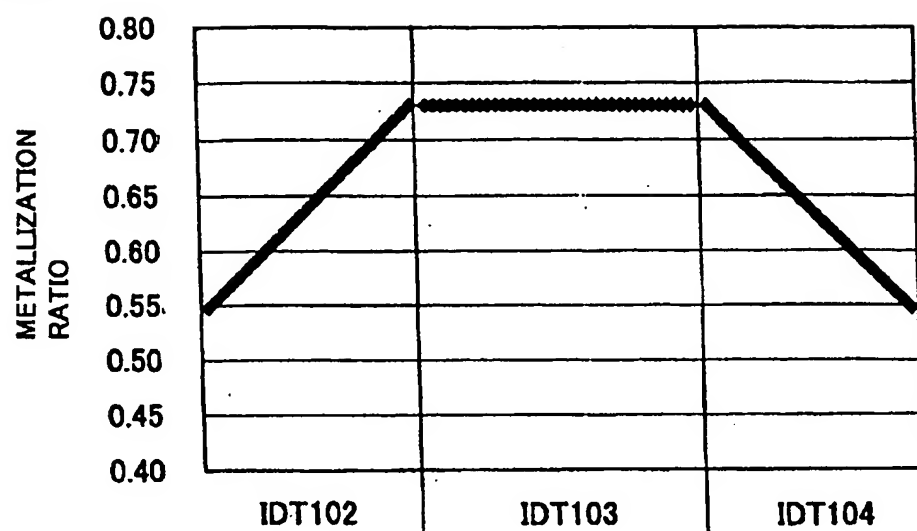


FIG. 6

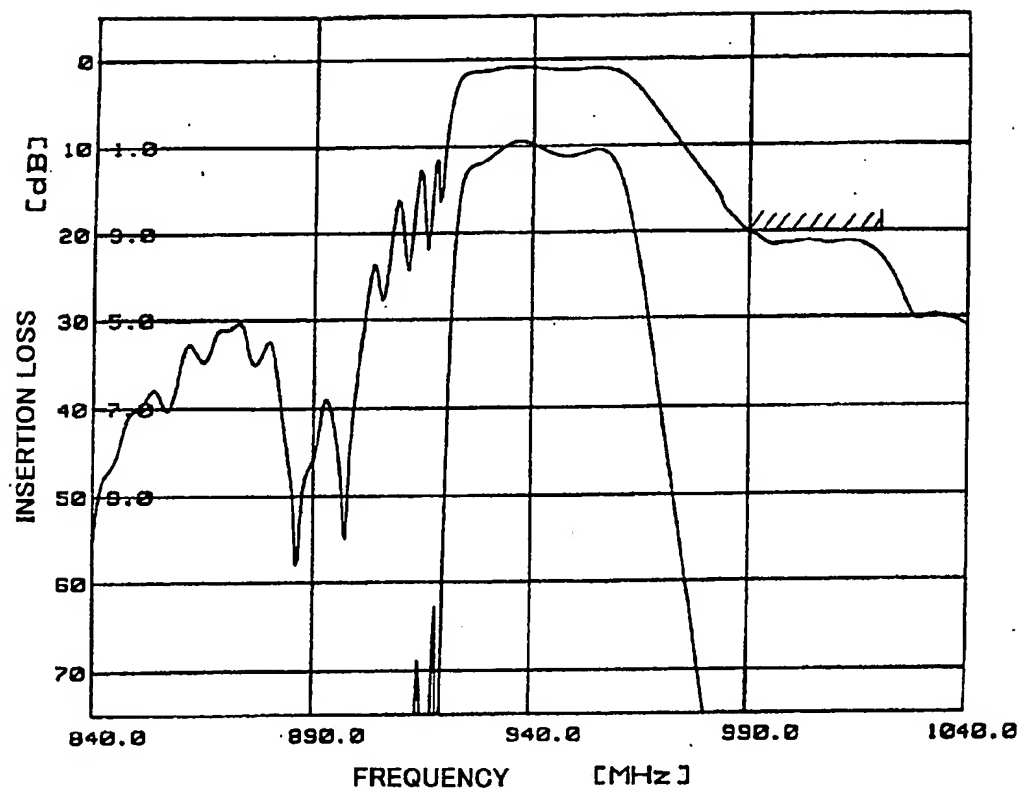


FIG. 7

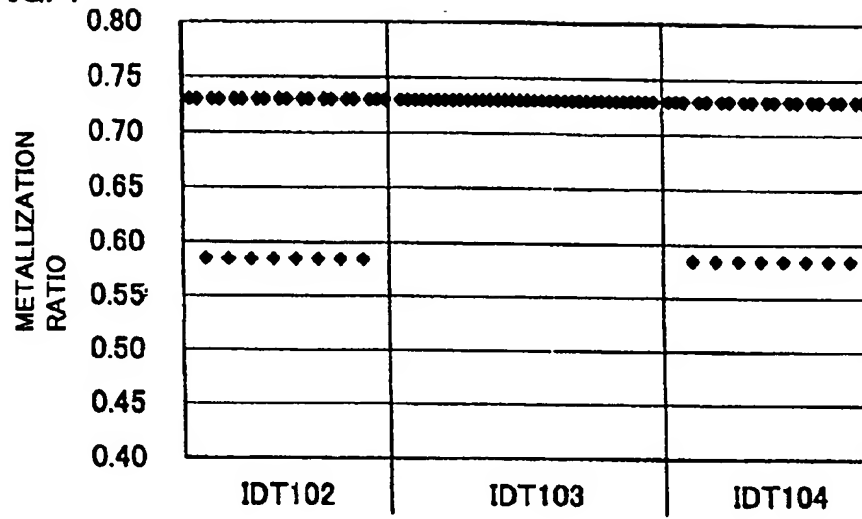
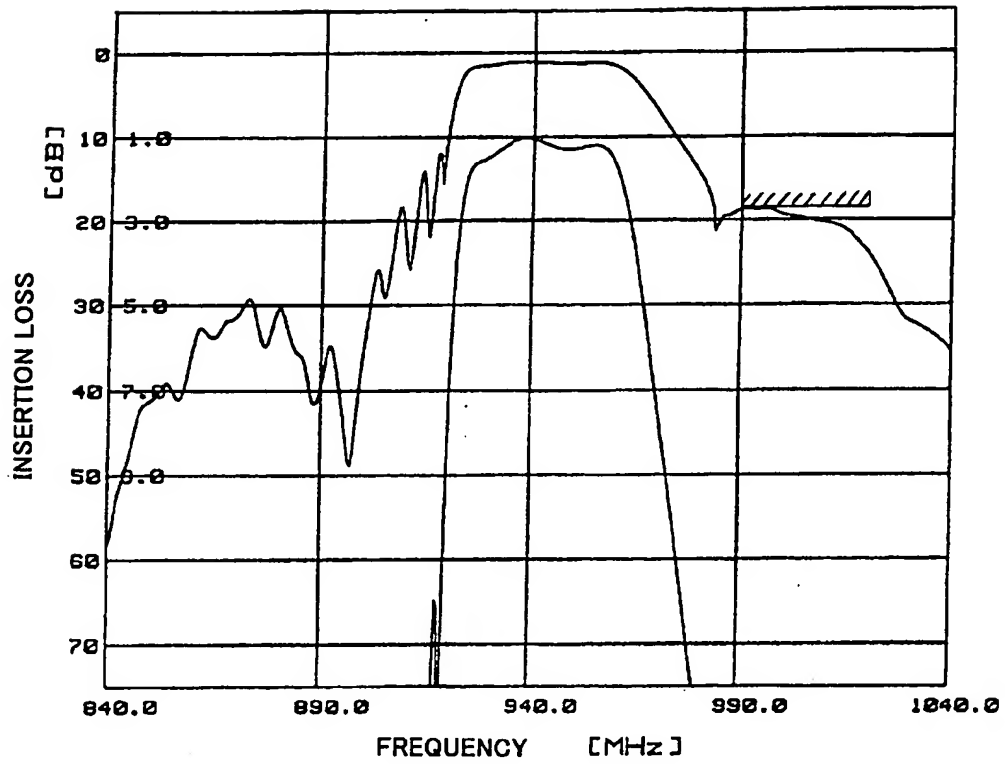
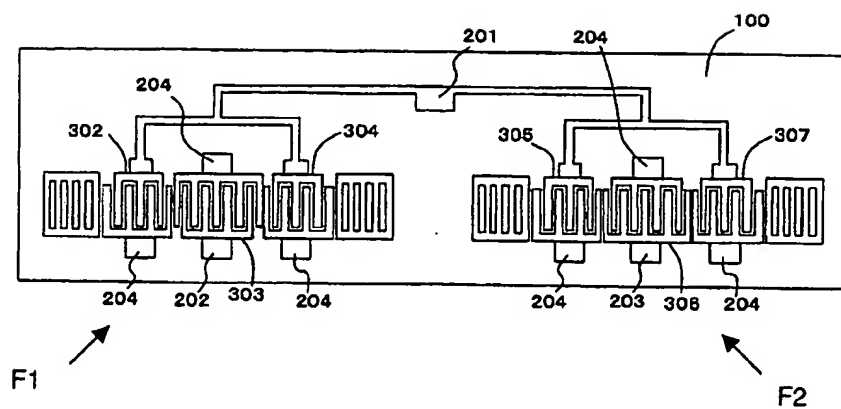


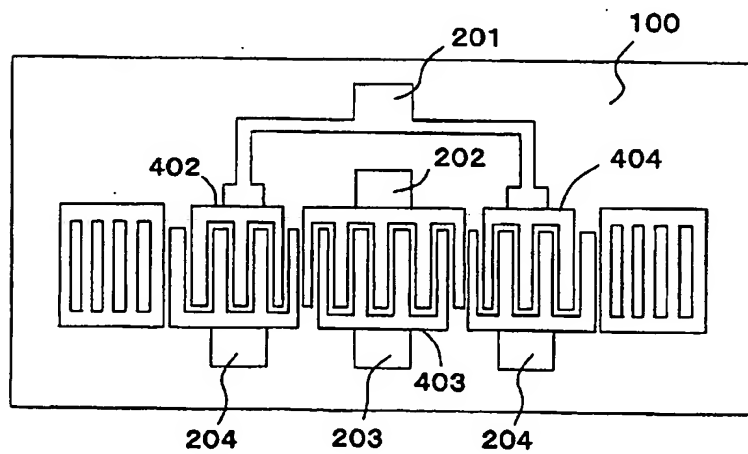
FIG. 8



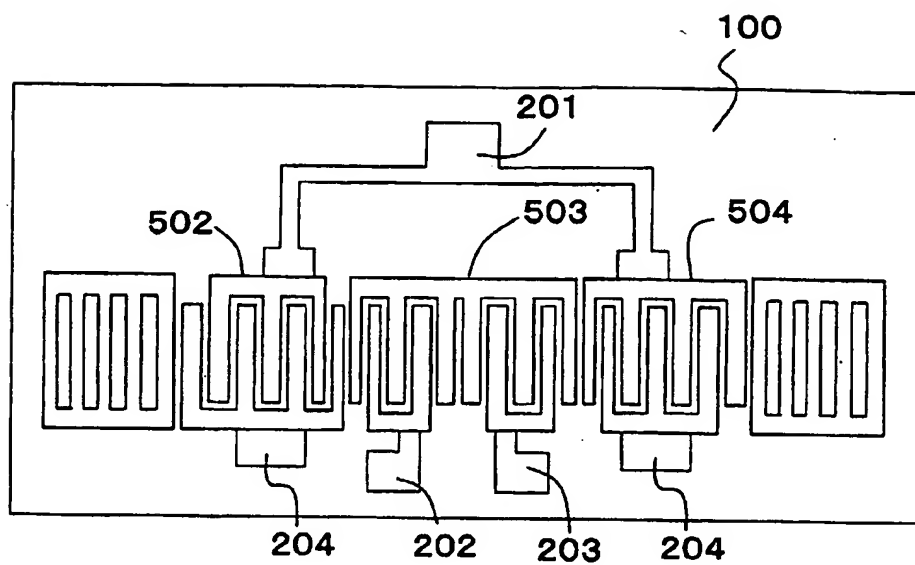
301 FIG. 9



401 FIG. 10



501 FIG. 11



601 FIG. 12

